

On low-energy predictions of unification models inspired by F-theory

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Abstract

The aim of this paper is to discuss phenomenological consequences of a particular unification model (\mathbb{Z}_3 model) inspired by F-theory. The most distinctive feature of this model is a variety of (cosmologically feasible) options for the NLSP and NNLSP, beyond the usually considered benchmark scenarios.

1 Introduction

With the LHC experiments laying siege to the Minimal Supersymmetric Standard Model (MSSM) and excluding large portions of its parameter space (see e.g. [1, 2]) it becomes increasingly important to identify the patterns of the masses of the superpartners motivated by fundamental theories and to confront them with the existing experimental data. Some novel patterns of this kind can emerge in unification models inspired by F-theory [3, 4, 5, 6]. The presented local models of [7] have several distinct features with possibly interesting impact on the low energy physics: extra $U(1)$ gauge symmetries which constrain the possible couplings and may lead to suppression of baryon number violating processes [8], rich messenger sector and several scalars whose interactions can lead to supersymmetry (SUSY) breaking; some of these scalars may also be the dark matter particles. These models employ gauge mediation of supersymmetry breaking (see e.g. [9] for a review) to generate the soft supersymmetry breaking masses for the scalar particles and the gauginos. Preliminary studies of phenomenology of these models have been done in [10] yielding bino-like neutralino or a stau as the next-to-lightest supersymmetric particle (NLSP), which is very similar to the usual models of gauge mediated supersymmetry breaking (GMSB); as always in these models the lightest supersymmetric particle is a GeV-scale gravitino. More recently, the influence of some exotic matter on GMSB has been analyzed in [11].

In this letter we revisit the issue of the lowest mass SUSY particles in the \mathbb{Z}_3 model proposed in [7, 8]. Analyzing all couplings allowed by the symmetries of the model, we find that certain Yukawa-type couplings between the messengers and the matter fields result in new contributions to the soft masses and A -terms for the scalar particles. Thanks to these corrections, new patterns of the superpartner masses become possible, including the cases of a relatively light stops, sneutrinos and selectrons/smuons which has not shown up too often in previous studies.

This letter is organized as follows. After a brief description of the model in Section 2, we present the expressions for the soft supersymmetry breaking terms at the messenger scale in Section 3. We study phenomenological consequences of the model by performing a random scan over its parameters; the scan is described in Section 4. Among the results we find many new patterns of the mass spectra of the superpartners and discuss their viability in Section 5. We conclude in Section 6.

2 The model

The details of the construction of the Dirac \mathbb{Z}_3 model can be found in [7, 8], but for convenience we shall present a synopsis here. The model contains two extra local $U(1)$ symmetry groups, whose gauge bosons acquire masses of the order of the GUT scale (denoted here by Λ_{GUT}) in Green-Schwarz mechanism. Thus at low energies the $U(1)$'s provide extra selection rules for the construction of Lagrangian. With the exception of the Higgs fields, all matter fields are arranged in complete 5, $\bar{5}$, 10 representations of $SU(5)$. The Higgses H_u , H_d are just the MSSM doublets and belong to incomplete 5 and $\bar{5}$ representations, and we shall identify $H_u = (5_H)_2$, $H_d = (\bar{5}_H)_2$. The matter content is summarized in Table 1.

	MSSM				Exotic							
	10_M	$\bar{5}_M$	5_H	$\bar{5}_H$	Y_{10}	Y'_{10}	$Y_{\bar{10}}$, $Y'_{\bar{10}}$	$Y_{\bar{5}}$	Y_5	X	N_R	\bar{D}_1
$U(1)_{PQ}$	+1	+1	-2	-2	+1	0	+3	+1	+3	-4	-3	-1
$U(1)_\chi$	-1	+3	+2	-2	-1	+4	+1	+3	-3	0	-5	+5

Table 1: Matter content of the model. The columns marked as ‘MSSM’ show the $U(1)_{PQ}$ and $U(1)_\chi$ charges of the $SU(5)$ multiplets containing the MSSM fields. The charges of the remaining fields are shown under the label ‘Exotic’.

We must recall that in F-theory case the effective Lagrangian contains all the invariant couplings, including the Yukawa interactions in the superpotential and the trilinear terms in Kähler potential (divided by the GUT scale Λ_{GUT}). For simplicity we shall take the respective couplings to be of the order one. The messenger fields are Y_5 , Y_{10} , Y'_{10} , where the subscript indicates the $SU(5)$ representation. Their masses are generated via vacuum expectation values of spurion superfields X , N_R coupled as¹:

$$W_S = X(Y_5 Y_{\bar{5}} + Y_{10} Y_{\bar{10}}) + N_R Y'_{10} Y'_{\bar{10}}. \quad (1)$$

The superpotential describing interactions between the messengers and the matter fields reads:

$$W_Y = \frac{\lambda_1}{2} (5_H)_2 Y_{10} Y_{10} + \lambda_2 (\bar{5}_H)_2 Y_{\bar{5}} Y_{10} + \lambda_3 (5_H)_2 10_M Y_{10} + \lambda_4 (\bar{5}_H)_2 Y_{\bar{5}} 10_M + \lambda_5 (\bar{5}_H)_2 Y_{10} \bar{5}_M. \quad (2)$$

Note that the messenger Y'_{10} does not show up in W_Y , hence its only couplings of interest are those with vector supermultiplets. However, we shall argue below that F_{N_R} is nearly

¹We have assumed that coupling of $Y_{\bar{10}}$, $Y'_{\bar{10}}$ is diagonal. This simplifies the model and precludes large 1-loop contributions to soft masses from $U(1)_Y$ D -terms [12].

zero, so there are no mass splittings between the bosonic and fermionic components of Y'_{10} and this multiplet can be ignored in the analysis of supersymmetry breaking.

Finally the hidden sector consists of spurions X, N_R, \overline{D}_1 which are singlets of $SU(5)$ and whose nonzero F -terms break SUSY. Nonvanishing $F_{\overline{D}_1}$ generates B/L violating processes [8] while nonvanishing F_{N_R} triggers breaking of the Standard Model gauge group by sleptons due to Kähler potential term [13]

$$K \supset \frac{1}{\Lambda_{GUT}} H_d^\dagger L N_R + \text{h.c.}, \quad (3)$$

thus we set them to zero. It follows that in the present analysis we can ignore N_R, \overline{D}_1 and Y'_{10} messengers and X is the only relevant spurion.

The model has three characteristic mass scales above the weak scale: Λ_{GUT} , $M_Y = \langle X \rangle$ and $\xi \equiv F_X / \langle X \rangle$. The first one is the unification scale, $\Lambda_{GUT} \approx 2 \times 10^{16}$ GeV, which we also identify with the mass M_{PQ} of the heavy gauge bosons of the extra $U(1)$'s. M_Y is the messengers scale and we assume it in the range 10^{13} GeV $\lesssim M_Y \lesssim 10^{14}$ GeV. The last one, ξ , is related to SUSY breaking scale $\sqrt{F_X}$. We shall not discuss the dynamics which triggers SUSY breaking (the simplest choice is the Polonyi model with linear SUSY breaking term induced e.g. by D-brane instantons) but assume for simplicity that SUSY is broken by F -term of the spurion X . The value $\sqrt{F_X} = 10^{9.5}$ GeV was fixed for the gravitino mass $m_{\tilde{G}} \sim F_X / M_P$ to be of the order 1 GeV [14].

3 Soft terms at the messenger scale

Supersymmetry is broken in the hidden sector by the F -term of the spurion X . In general, SUSY breaking can be transmitted to the visible sector by a variety of mechanisms. Due to couplings of messengers and matter in superpotential, our model represents a full-fledged mechanism of so-called deflected gauge mediation [15]. Gaugino masses arise from 1-loop diagrams, scalar masses mainly come from 2-loop diagrams and there are 1-loop contributions to A -terms originating from direct couplings between the messengers and the matter fields [15, 16, 17, 18]. Below we summarize these results at the messenger scale M_Y , adopting a widely used convention $\alpha_g = g^2/4\pi$, where g is a coupling constant.

Gaugino masses are given by standard 1-loop expressions:

$$M_\lambda^{(r)} = \frac{\alpha_r}{4\pi} n_X \xi, \quad (4)$$

where $r = 1, 2, 3$ corresponds to the gauge group $U(1)_Y, SU(2)_L$ and $SU(3)_C$ of the Standard Model (we use the GUT normalization for the hypercharge) and $n_X = 4$ is twice the sum of the Dynkin indices of the messenger fields coupling to spurion X .

Soft SUSY breaking mass terms of scalars $\phi \in \{H_u, H_d, L, E, Q, U, D\}$ can be written as

$$m_\phi^2 = m_{\phi,g}^2 + m_{\phi,\lambda}^2 + m_{\phi,PQ}^2. \quad (5)$$

Here $m_{\phi,g}^2$ are standard 2-loop gauge mediation results induced by gauge interactions transmitting SUSY breaking from messenger sector

$$m_{\phi,g}^2 = 2 \sum_{r=1}^3 C_2^r(\phi) \frac{\alpha_r^2}{(4\pi)^2} n_X \xi^2, \quad (6)$$

where $C_2^r(\phi)$ are quadratic Casimir operators of the representation of ϕ under r -th gauge group. The contributions $m_{\phi,\lambda}^2$ in (5) are 2-loop terms induced by the Yukawa-type couplings in (2) [15]:

$$m_{\phi,\lambda}^2 = -\frac{1}{4} \sum_{\lambda} \left(\frac{\partial \Delta \gamma_{\phi}}{\partial \lambda} \beta_{\lambda}^+ + \text{h.c.} \right) \xi^2, \quad (7)$$

where λ denote all the Yukawa couplings in the superpotential. In (7) β^+ are the beta functions above the messenger mass scale M_Y , $\Delta \gamma_{\phi} = \gamma_{\phi}^+ - \gamma_{\phi}^-$, γ_{ϕ}^+ is the anomalous dimension of ϕ above scale M_Y and γ_{ϕ}^- is the anomalous dimension of ϕ below scale M_Y . Discontinuities of γ_{ϕ} are due to the absence of the messengers in the effective action below scale M_Y . Note that 1-loop contributions to the soft SUSY breaking scalar masses ([19]) are negligibly small compared to $m_{\phi,g}^2$ and can be safely ignored. We have checked that all λ_i couplings can significantly change the pattern of superpartner masses. With the recipe outlined above, eq. (7) can be rewritten in the following form:

$$m_{\phi,\lambda}^2 = \frac{\xi^2}{16\pi^2} \sum_A \kappa_{\phi,A} f_A(\alpha_i). \quad (8)$$

In this formula, the functions f_A are appropriate products of α_{λ_i} with $i = 1, \dots, 5$, α_{y_j} with $j = u, d, e$ (or square roots thereof) and three combinations of the gauge couplings which we denote by $\alpha'_G = (13/60)\alpha_1 + (3/4)\alpha_2 + (4/3)\alpha_3$, $\alpha''_G = (7/60)\alpha_1 + (3/4)\alpha_2 + (4/3)\alpha_3$ and $\alpha'''_G = (1/20)\alpha_1 + (1/12)\alpha_2$. These functions and the values of the numerical coefficients $\kappa_{\phi,A}$ in the expansion (8) are given in Table 2.

The contribution $m_{\phi,PQ}^2$ in (5) comes from an operator generated at the tree level by exchange of the heavy gauge boson of anomalous $U(1)_{PQ}$ symmetry:

$$\mathcal{L} \supset -\frac{g_{PQ}^2 q_X q_{\phi}}{M_{PQ}^2} \int d^4\theta X^{\dagger} X \phi^{\dagger} \phi. \quad (9)$$

It is known that this operator can significantly affect the low-energy spectrum of the model [10]. We shall parametrize soft masses $m_{\phi,PQ}^2$ generated by (9) as

$$m_{\phi,PQ}^2 = q_X q_{\phi} \tilde{\Delta}^2, \quad (10)$$

where q_X, q_{ϕ} are $U(1)_{PQ}$ charges and $\tilde{\Delta} = g_{PQ} \frac{|F_X|}{M_{PQ}} = g_{PQ} \frac{|F_X|}{\Lambda_{GUT}}$. With given F_X and Λ_{GUT} this quantity depends only on g_{PQ} , which we expect to be of the same order as the unified value of all gauge couplings at Λ_{GUT} . Thus the natural scale for $\tilde{\Delta}$ is $\mathcal{O}(10^2 \text{ GeV})$.

Finally, there are A -terms generated by 1-loop diagrams involving the Yukawa-type couplings in (2). We can write their contributions to the trilinear terms in the potential as:

$$\begin{aligned} V \supset & -\frac{y_u}{4\pi} (3\alpha_{\lambda_1} + 9\alpha_{\lambda_3} + \alpha_{\lambda_4}) \xi H_u Q U - \frac{y_d}{4\pi} (4\alpha_{\lambda_2} + \alpha_{\lambda_3} + 5\alpha_{\lambda_4} + 6\alpha_{\lambda_5}) \xi H_d Q D \\ & -\frac{y_e}{4\pi} (4\alpha_{\lambda_2} + 6\alpha_{\lambda_4} + 5\alpha_{\lambda_5}) \xi H_d L E. \end{aligned} \quad (11)$$

These results specify the initial conditions which we shall use in the following section to study the phenomenological aspects of the model.

$\phi \rightarrow$ $\downarrow f_A$	H_u	H_d	L	E	Q	U	D
$\alpha_{\lambda_1}^2$	18	0	0	0	0	0	0
$\alpha_{\lambda_1} \alpha_{\lambda_2}$	3	3	0	0	0	0	0
$\alpha_{\lambda_1} \alpha_{\lambda_3}$	72	0	0	0	6	12	0
$\alpha_{\lambda_1} \alpha_{\lambda_5}$	3	3	0	0	0	0	2
$\alpha_{\lambda_2}^2$	0	28	0	0	0	0	0
$\alpha_{\lambda_2} \alpha_{\lambda_3}$	3	3	0	0	0	2	0
$\alpha_{\lambda_2} \alpha_{\lambda_4}$	0	56	0	14	7	0	0
$\alpha_{\lambda_2} \alpha_{\lambda_5}$	0	56	7	0	0	0	14
$\alpha_{\lambda_3}^2$	54	0	0	0	9	18	0
$\alpha_{\lambda_3} \alpha_{\lambda_4}$	3	3	0	0	2	0	0
$\alpha_{\lambda_3} \alpha_{\lambda_5}$	3	3	0	0	0	2	2
$\alpha_{\lambda_4}^2$	0	28	0	14	7	0	0
$\alpha_{\lambda_4} \alpha_{\lambda_5}$	0	32	4	8	4	0	8
$\alpha_{\lambda_5}^2$	0	28	7	0	0	0	14
$\alpha_{\lambda_1} \alpha_{y_u}$	0	0	0	0	-3	-6	0
$\alpha_{\lambda_2} \alpha_{y_d}$	0	0	0	0	-4	0	-8
$\alpha_{\lambda_2} \alpha_{y_e}$	0	0	-4	-5	0	0	0
$\alpha_{\lambda_3} \alpha_{y_u}$	0	0	0	0	-6	-12	0
$\alpha_{\lambda_3} \alpha_{y_d}$	3	-3	0	0	0	0	-2
$\alpha_{\lambda_4} \alpha_{y_u}$	-3	3	0	0	0	-2	0
$\alpha_{\lambda_4} \alpha_{y_d}$	0	0	0	6	-1	0	-14
$\alpha_{\lambda_4} \alpha_{y_e}$	0	0	-7	-6	1	0	0
$\alpha_{\lambda_5} \alpha_{y_d}$	0	0	3	0	-7	0	-2
$\alpha_{\lambda_5} \alpha_{y_e}$	0	0	-3	-14	0	0	2
$\alpha'_G \alpha_{\lambda_1}$	-12	0	0	0	0	0	0
$\alpha'_G \alpha_{\lambda_3}$	-24	0	0	0	-4	-8	0
$\alpha''_G \alpha_{\lambda_2}$	0	-12	0	0	0	0	0
$\alpha''_G \alpha_{\lambda_4}$	0	0	0	0	-4	0	0
$\alpha''_G \alpha_{\lambda_5}$	0	-12	0	0	0	0	-8
$\alpha'''_G \alpha_{\lambda_2}$	0	-36	0	0	0	0	0
$\alpha'''_G \alpha_{\lambda_4}$	0	-36	0	-72	0	0	0
$\alpha'''_G \alpha_{\lambda_5}$	0	-36	-36	0	0	0	0
$\sqrt{\alpha_{\lambda_1} \alpha_{\lambda_2} \alpha_{\lambda_3} \alpha_{\lambda_4}}$	6	6	0	0	2	0	0
$\sqrt{\alpha_{\lambda_1} \alpha_{\lambda_3} \alpha_{\lambda_3} \alpha_{y_u}}$	18	0	0	0	0	0	0
$\sqrt{\alpha_{\lambda_1} \alpha_{\lambda_3} \alpha_{\lambda_5} \alpha_{y_d}}$	6	0	0	0	0	0	0
$\sqrt{\alpha_{\lambda_2} \alpha_{\lambda_3} \alpha_{\lambda_4} \alpha_{y_u}}$	0	6	0	0	0	0	0
$\sqrt{\alpha_{\lambda_2} \alpha_{\lambda_4} \alpha_{\lambda_5} \alpha_{y_d}}$	0	18	0	0	0	0	0
$\sqrt{\alpha_{\lambda_2} \alpha_{\lambda_4} \alpha_{\lambda_5} \alpha_{y_e}}$	0	6	0	0	0	0	0
$\sqrt{\alpha_{\lambda_3} \alpha_{\lambda_5} \alpha_{y_u} \alpha_{y_d}}$	0	0	0	0	-2	0	0

Table 2: Numerical coefficients $\kappa_{\phi,A}$ in (8).

4 Numerical analysis

Adopting the initial conditions for the soft SUSY breaking masses presented in Section 3, we now turn to studying the phenomenological consequences of such an ansatz. We compute the low-energy spectrum and the electroweak symmetry breaking with an appropriately modified **SuSpect** code [20]. We work in the approximation of vanishing Yukawa couplings of the first two generations of fermions, so the MSSM mass spectra we obtain are degenerate for these generations. In the following, we shall refer to sfermions of these generations with the name of the first generation.

In order to make the large parameter space manageable, we choose $\xi = 10^5 \text{ GeV}$ and $M_Y = 10^{14} \text{ GeV}$. Such a range is consistent with models of gravitational stabilization of the SUSY breaking vacuum put forward in [21], which have $\langle X \rangle \sim M_Y \sim \Lambda_{GUT}^2/M_P$. This choice of ξ leads to the bino/wino/gluino masses of approximately 0.55/1.0/2.7 TeV. We also take $\text{sgn}(\mu) = +1$.

Parameters λ_i are varied between 0.2 and 1.5 with a flat prior, but the maximal values of λ_1 and λ_3 consistent with the bounds discussed below are 1.1 and 0.9, respectively. The nonzero lower limit reflects the assumption that natural values of the couplings λ_i lie close to unity, so these couplings should not be fine tuned to very small values. The values of $\tan \beta$ are drawn from the range 5 – 45 with a flat prior. We also scan $\tilde{\Delta}^2$ between $2.5 \times 10^3 \text{ GeV}^2$ and $2.5 \times 10^4 \text{ GeV}^2$ with a flat prior.

We impose a number of constraints on the obtained mass spectra. We require that the scalar potential is bounded from below and that there are no low lying color or charge breaking minima. The latter leads to quite involved conditions [22], but we checked and then used its simplified (and more practical computationally) version implemented in **SuSpect** which does not introduce large errors. All models with tachyons in the spectrum, the light Higgs boson mass below 114 GeV and $\text{BR}(b \rightarrow s\gamma)$ lying outside the 2σ range $(2.87 - 4.33) \times 10^{-4}$ were discarded. We keep only models in which the squark and gluino masses lie within the allowed 95% CL range determined for a simplified setup in Ref. [1]. Note that these bounds are roughly consistent with those obtained in the phenomenological MSSM with 19 independent parameters [2].

The patterns of NLSP/NNLSP occurring in the scan with frequency bigger than 0.01 are shown in Table 3 and plotted in Fig. 1. They encompass much wider variety of possibilities than usually considered in models of GMSB. In particular, there are 3 classes of novel patterns: selectron (N)NLSP, stop (N)NLSP and higgsino (N)NLSP.

5 Discussion

We would like to start by enumerating similarities and differences between the supersymmetric mass spectra obtained here and usually discussed models of gauge mediation. As a benchmark, we shall use the characteristics of the supersymmetric mass spectra presented in [23].

Similarities include: (i) gluinos are much heavier than the lighter neutralinos, charginos and sleptons of the first two generations, (ii) thanks to large RGE effects squarks of the first two families are heavy as gluinos, (iii) the lighter stop is most often the lightest of squarks.

We also find a number of notable differences from the usually considered spectra of GMSB. For many cosmological and phenomenological purposes, these differences can be

	NLSP	NNLSP	λ_1	λ_2	λ_3	λ_4	λ_5	$(\frac{10^3 \tilde{\Delta}}{\xi})^2$	$\tan \beta$	g_{PQ}	fraction
(a)	$\tilde{\chi}_1^0$	\tilde{e}_1	0.564	0.211	0.409	1.189	0.255	2.22	10.5	0.30	0.31
(b)	$\tilde{\chi}_1^0$	$\tilde{\nu}_e$	0.243	1.205	0.678	0.255	0.243	2.20	12.9	0.30	0.30
(c)	$\tilde{\nu}_e$	\tilde{e}_1	0.440	0.673	0.439	1.004	1.201	0.31	13.0	0.11	0.080
(d)	$\tilde{\chi}_1^0$	$\tilde{\tau}_1$	0.592	0.812	0.557	0.592	0.279	2.20	31.2	0.30	0.069
(e)	$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	0.448	0.401	0.549	0.370	0.649	1.20	22.2	0.22	0.060
(f)	$\tilde{\chi}_1^0$	\tilde{t}_1	0.205	0.573	0.851	0.717	0.550	0.45	11.4	0.13	0.037
(g)	$\tilde{\chi}_1^0$	$\tilde{\nu}_\tau$	0.697	0.237	0.483	0.999	0.590	2.37	31.1	0.31	0.035
(h)	\tilde{e}_1	$\tilde{\chi}_1^0$	0.846	0.252	0.470	0.988	0.507	2.40	18.1	0.31	0.026
(i)	\tilde{t}_1	$\tilde{\chi}_1^0$	0.800	0.520	0.500	0.931	0.933	2.21	19.0	0.30	0.019
(j)	$\tilde{\tau}_1$	\tilde{e}_1	0.562	0.369	0.675	0.283	0.457	1.13	11.7	0.21	0.018
(k)	$\tilde{\nu}_\tau$	$\tilde{\tau}_1$	0.587	0.605	0.343	1.327	0.212	2.22	14.5	0.30	0.013
(l)	$\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm$	0.949	0.557	0.396	0.462	0.602	1.31	13.1	0.23	0.010

Table 3: Examples of λ_i , $\tilde{\Delta}$ and $\tan \beta$ leading to different NLSP/NNLSP patterns for $\xi = 10^5 \text{ GeV}$ and $F_X = 10^{19} \text{ GeV}^2$. The lightest neutralino, $\tilde{\chi}_1^0$ is always an almost pure bino, except for the last example in which both the NLSP neutralino and the NNLSP chargino are higgsino-like.

most easily described by comparing the patterns of the NLSP/NNLSP particles. In ordinary models of GMSB with the assumed scales ξ and M_Y and moderate (large) value of $\tan \beta$, one obtains bino/stau (stau/bino) patterns. In our sample, bino/stau and stau/bino are also frequent patterns (13% of all cases), but the lighter stau is often (approximately in 1 out of 3 cases) the superpartner of a left-handed state, such as in the example (d) in Table 3.

Our analysis reveals novel patterns with stop/sneutrino/selectron/higgsino (N)NLSP. Some of them may have advantages from the cosmological point of view. A colored NLSP, such as the stop [24] ($\sim 2\%$ in our sample), could help explain the problematic primordial abundance of lithium [25]. Although it may seem that the stop mass range required by the lithium data leads to a larger stop relic abundance than what is allowed by the Big Bang Nucleosynthesis [26], there may be additional annihilations of stops after the QCD phase transitions when the stops are in a confined phase with quarks [27, 28]. The existing LHC data do not exclude a light and long-lived stop [29].

A bino NLSP, which has a large hadronic branching fraction in its decay, is also severely constrained by BBN: short lifetimes are preferred, so the gravitino mass cannot be too large, which in turn makes somewhat difficult to obtain a large reheating temperature [30], unless the bino is degenerate in mass with a strongly interacting particle and the two can coannihilate [31] (see also [32]). In our analysis we find a sizable fraction ($\sim 4\%$) of models with the \tilde{B}/\tilde{t} pattern; some of them exhibit a desired mass degeneracy. A parameter choice leading to an appropriately degenerate spectrum is given as example (f) in Table 3. For such a spectrum, we find with the use of the `micrOmegas` code [33, 34] a leading-order² NLSP density parameter after freeze-out $\Omega_{\text{NLSP}} \approx 10^{-2}$, which allows a reheating temperature consistent with the BBN bounds as large as $5 \times 10^7 \text{ GeV}$. This value is by 3 orders of magnitude larger than one obtained in models with a non-degenerate binos and a universal

²This estimate neglects the Sommerfeld enhancement of the annihilation cross-section, which can give a suppression of the relic density by a factor of 2 – 3, cf. [31].

gaugino mass pattern at the high scale [31].

The tension between BBN and a large reheating temperature can be alleviated for a light sneutrino NLSP [35] (see also [37]) – such models are also present in our analysis, as shown by example (k) in Table 3. In that example we find $\Omega_{\text{NLSP}} = 0.03$ [33, 34] and the hadronic branching ratio in the sneutrino NLSP decay of 4×10^{-4} , and conclude that the cosmological bounds (BBN, CMB) diffuse neutrino background and are satisfied for the gravitino mass range considered here [35].

Although the supersymmetric spectra described above are different from usually considered, they are compatible with the current LHC results (see e.g. [2]), and we do not expect them to give any novel striking signal in the nearest future (with a possible exception of a charged detector-stable NLSP, a selectron or stau). Hopefully, with future data it will be possible to determine whether these spectra can be realized in nature.

6 Conclusions

In this letter, we reported on a study of novel MSSM mass spectra predicted in a particular unification model inspired by F-theory. In addition to bino/stau and stau/bino NLSP/NNLSP pattern found in minimal GMSB models, we obtained a number of other patterns rarely discussed in the literature. The degenerate bino/stop pattern and the pattern with a light NLSP sneutrino may have some advantages from the cosmological point of view, as they allow for a much higher reheating temperatures than the usually considered models. In spite of the simplicity of the theoretical setup employed here, we obtain a great variety of possible supersymmetric spectra, which suggests that the benchmark models used so far in the study of the LHC data may leave out some realistic, well-motivated and cosmologically viable possibilities.

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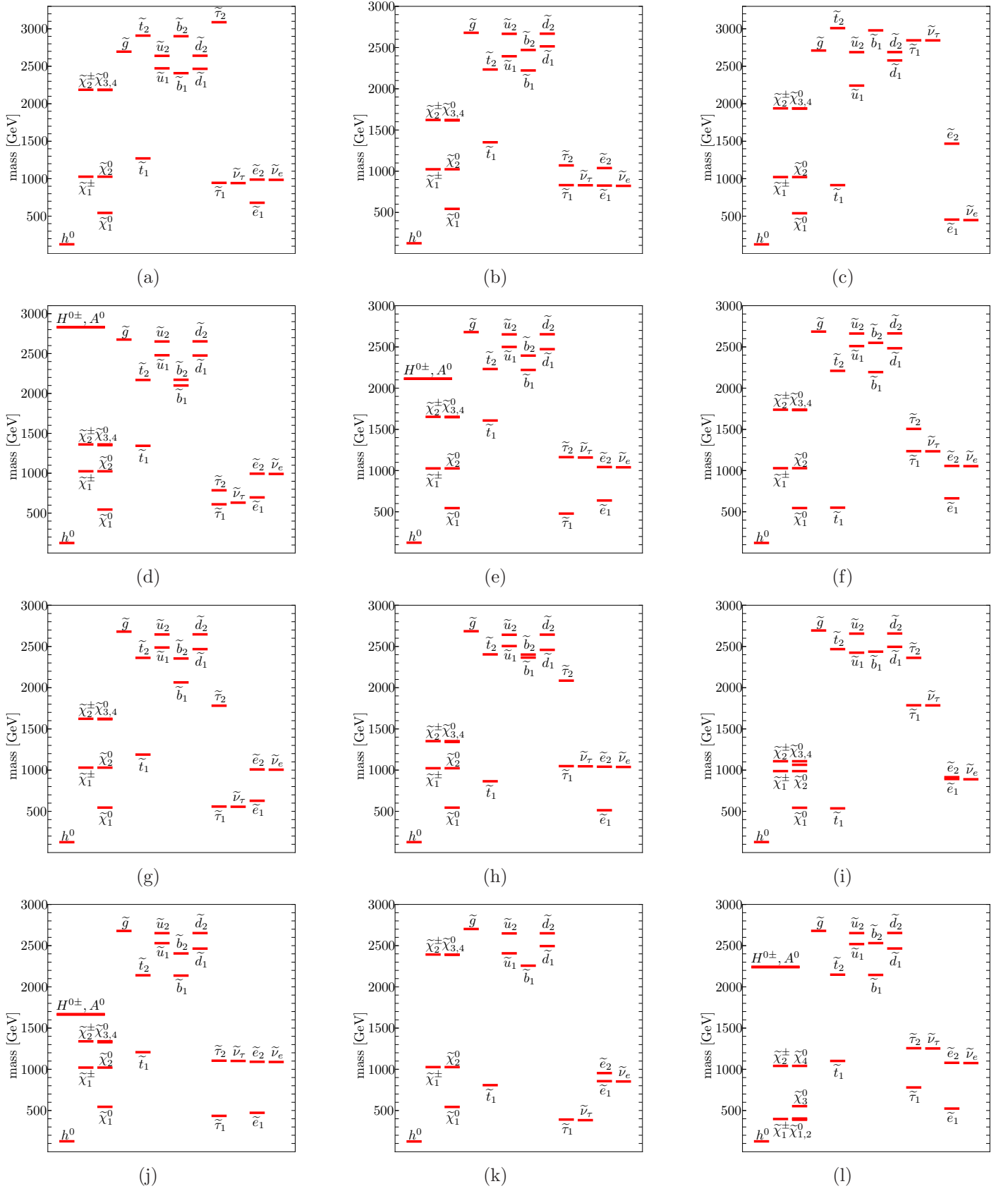


Figure 1: Examples of the mass spectra corresponding to parameters λ_i , $\tilde{\Delta}$ and $\tan \beta$ given in Table 3.